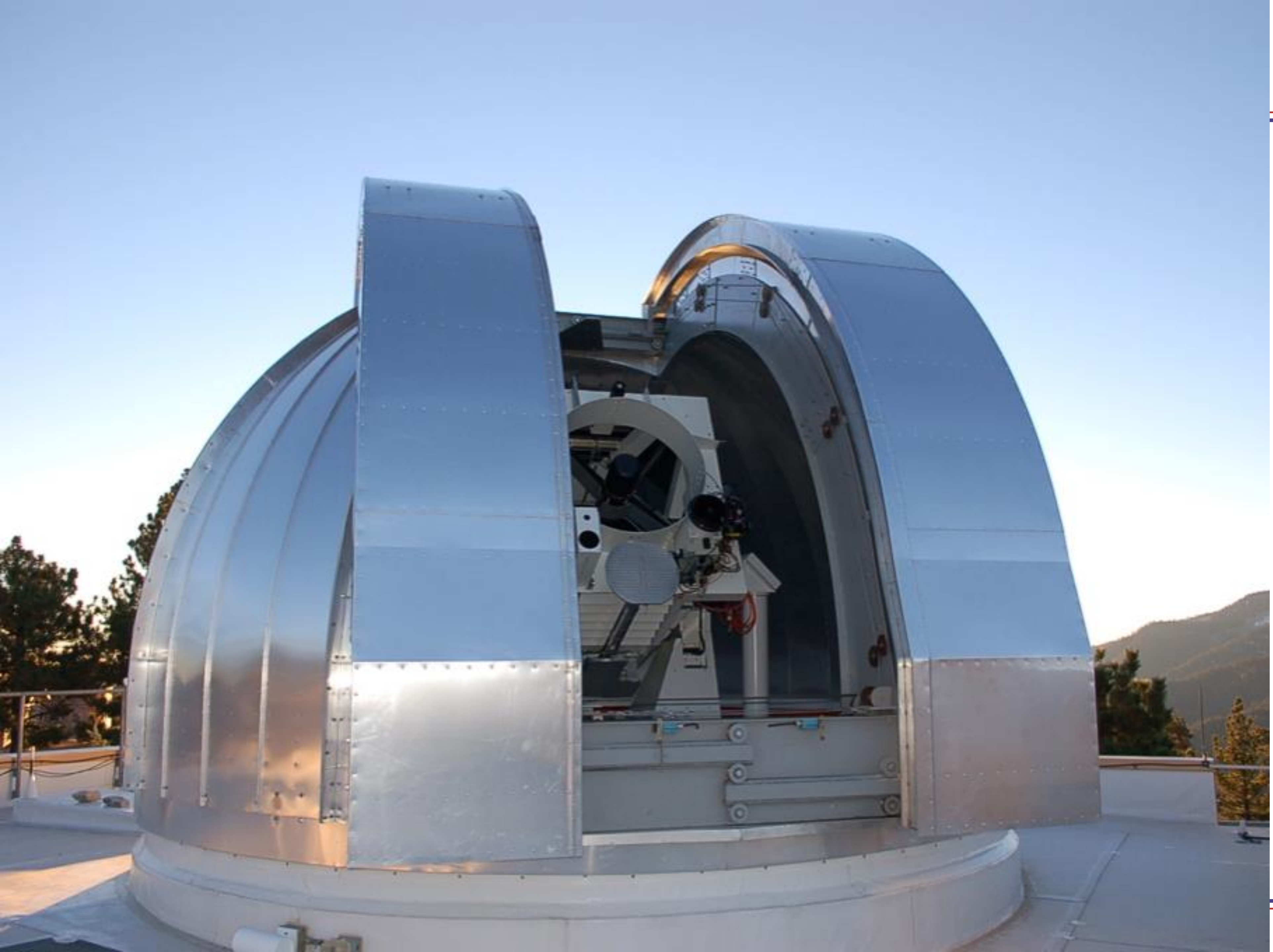


Jet Propulsion Laboratory
California Institute of Technology

LCRD Optical Ground Station-1

NASA in Your Neighborhood Series

Presented by

Tom Roberts

Jet Propulsion Laboratory, The California Institute of Technology

January 20, 2021

Presentation Outline

- LCRD Mission
- LOGS Project
- Subsystem Designs
    - OCTL telescope
    - Adaptive optics system
    - Beam propagation system
    - Laser safety system
    - Beacon lasers
    - Monitor and control system
    - Atmospheric characterization monitoring system
- System Summary

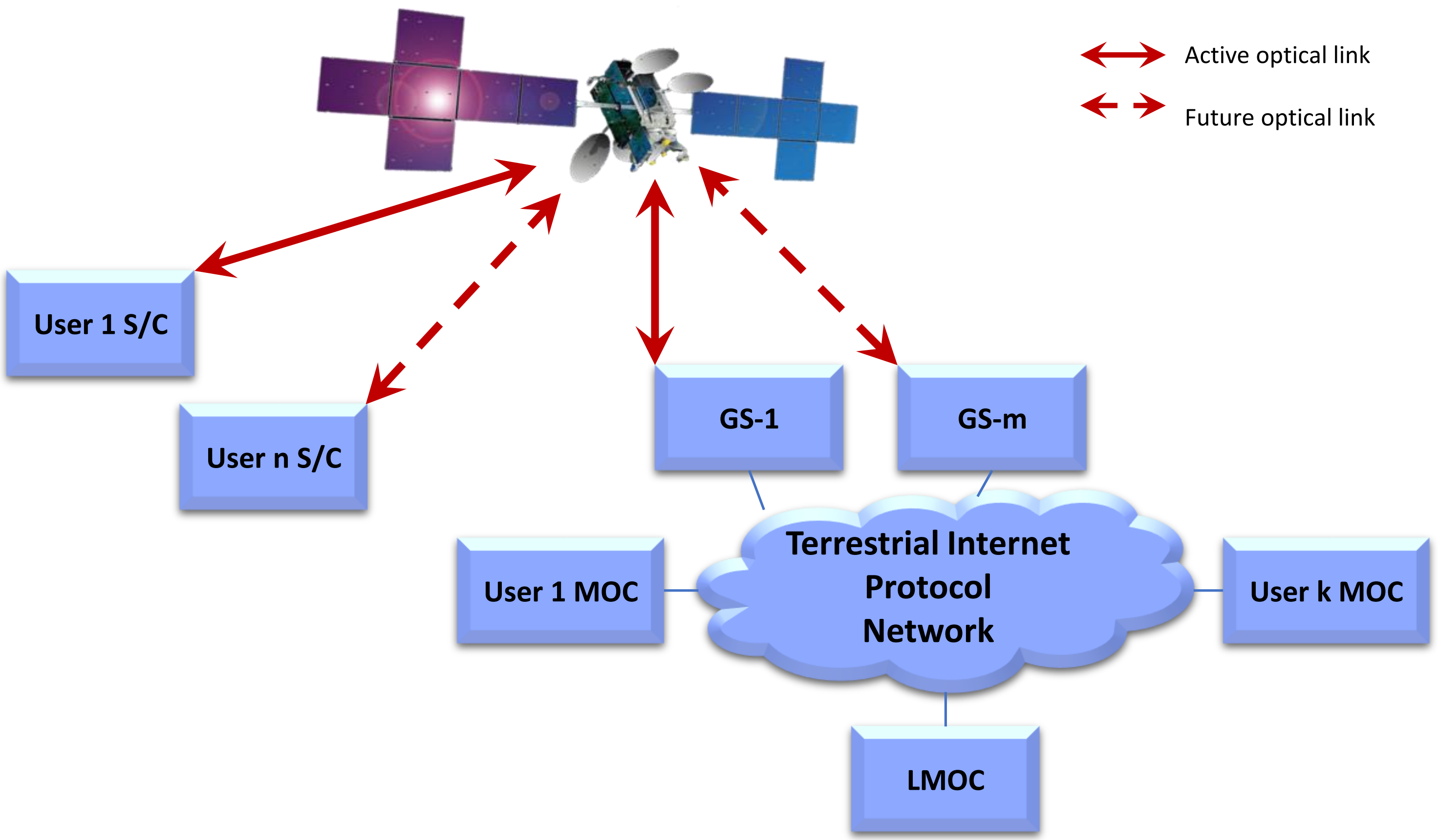
LCRD Mission

- The Laser Communications Relay Demonstration (LCRD) will demonstrate optical communications relay services between GEO and Earth over an extended period, and thereby gain the knowledge and experience base that will enable NASA to design, procure, and operate cost-effective future optical communications systems and relay networks.

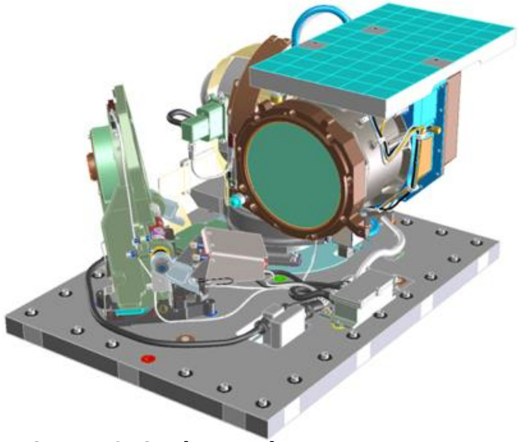
- LCRD is the next step in NASA eventually providing an optical communications service on the Next Generation Tracking and Data Relay Satellites

Design Reference Mission

- Simultaneous multiple real-time user support and multiple store & forward user support multiplexed on single trunkline
- Different user services: frame, DTN, …
- Scheduled and Unscheduled Ground Station handovers
- Number of Users, Mission Operations Centers (MOCs), and Payloads scalable
- Emulation of different relay and user location and orbits by the insertion of delays and disconnections in the data paths

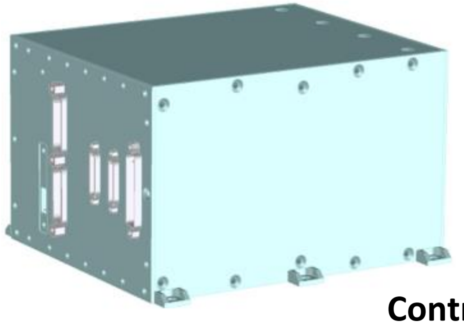


LCRD Payload Hardware



Optical Module (qty 2)

- Gimbaled telescope (elevation over azimuth)
  - 12° half-angle Field of Regard
- 10.8 cm aperture, 14 kg
- Local inertial sensor stabilization

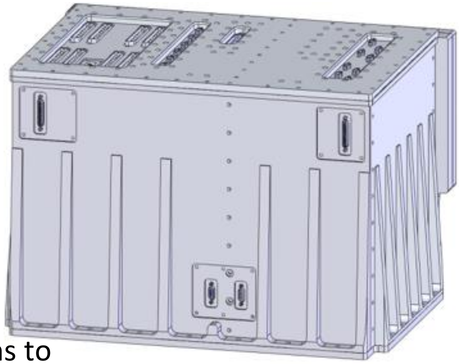


Controller Electronics (CE) (qty 2)

- OM control/monitoring
- Interface to Host Spacecraft
- 7 kg, 151 W

Integrated Modem (qty 2)

- 0.5 W transmitter; optically pre-amplified receiver
- DPSK and PPM modulation
- 27 kg, 130 W
- Supports Tx and Rx frame processing
  - No on-board coding and interleaving



Space Switching Unit (qty 1)

- Flexible interconnect between modems to support independent communication links
  - High speed frame switching/routing
- Command and telemetry processor

LCRD Mission Architecture

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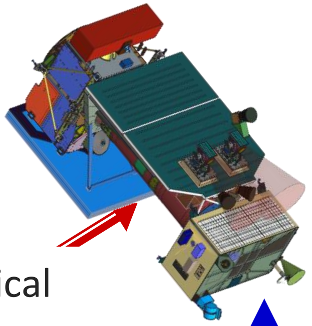
LCRD Flight Payload
2 Optical Relay Terminals
- 10.8 cm aperture
- 0.5 W transmitter
- DPSK and PPM

Space Switching Unit



Relay Link Features:
- Coding/Interleaving at the link edges
  - Rate ½ DVB-S2 codec (LDPC)
  - 1 second of interleaving for atmospheric fading mitigation

Optical

Optical

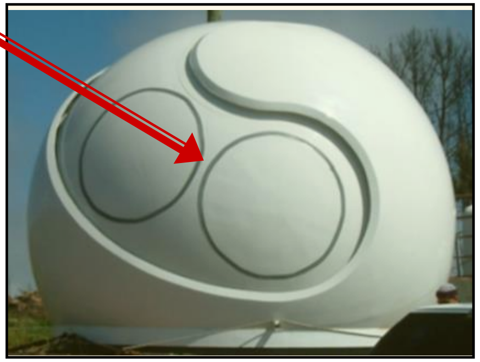
2880 Mbps Uncoded DPSK
1244 Mbps Coded DPSK
311 Mbps 16-PPM

RF

Table Mountain, CA

Optical Ground Station 1
- 1 m transmit and receive aperture
- 10 W transmitter

Host Mission Ops Center (HMOC)



Hawaii (TBR)

Optical Ground Station 2
- 60 cm receive aperture
- 15 cm transmit aperture
- 10 W transmitter

Remote LCRD Mission Ops Center (R-LMOC)

GSFC

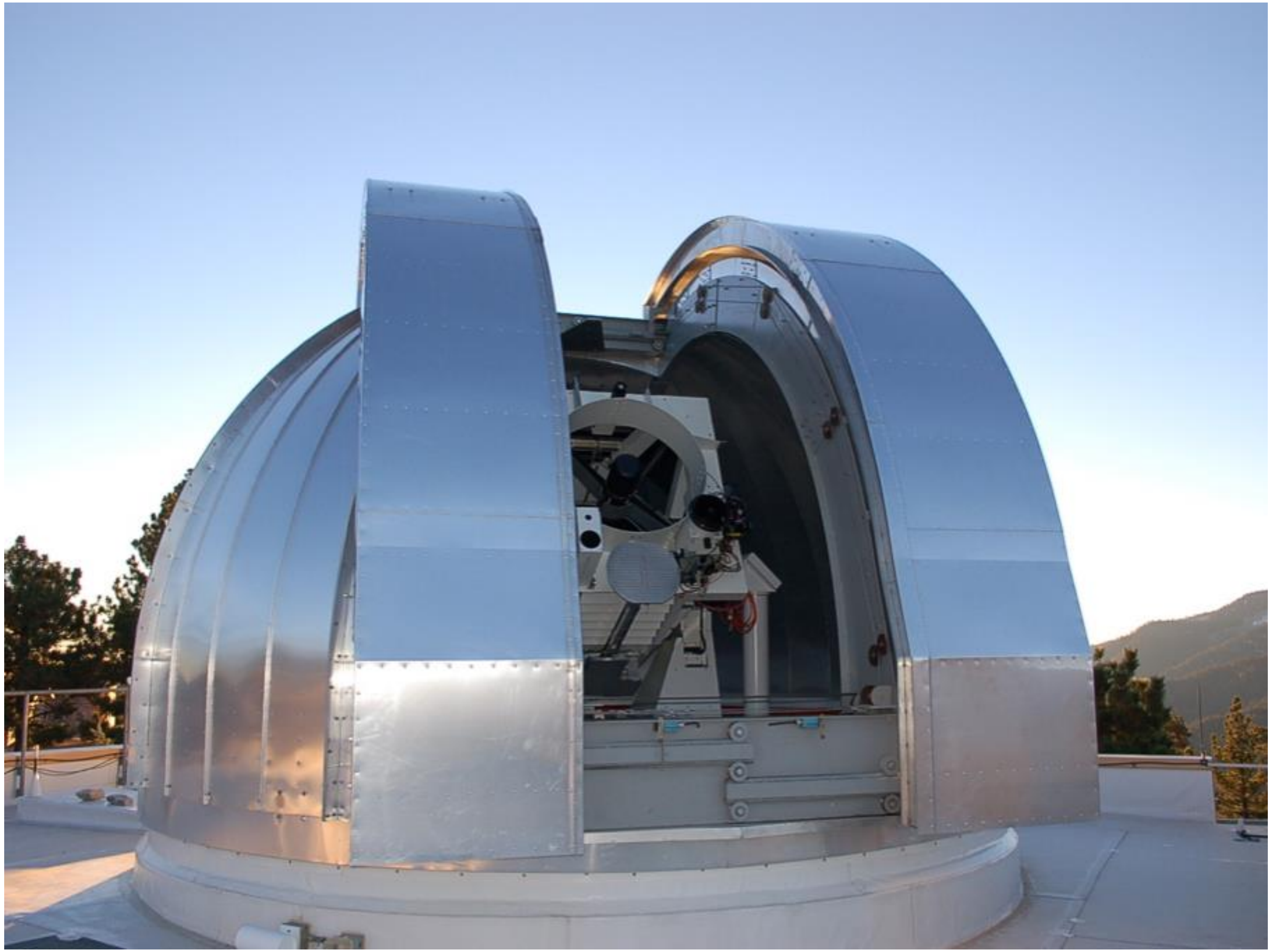
LCRD Mission Ops Center (LMOC)

White Sands, NM

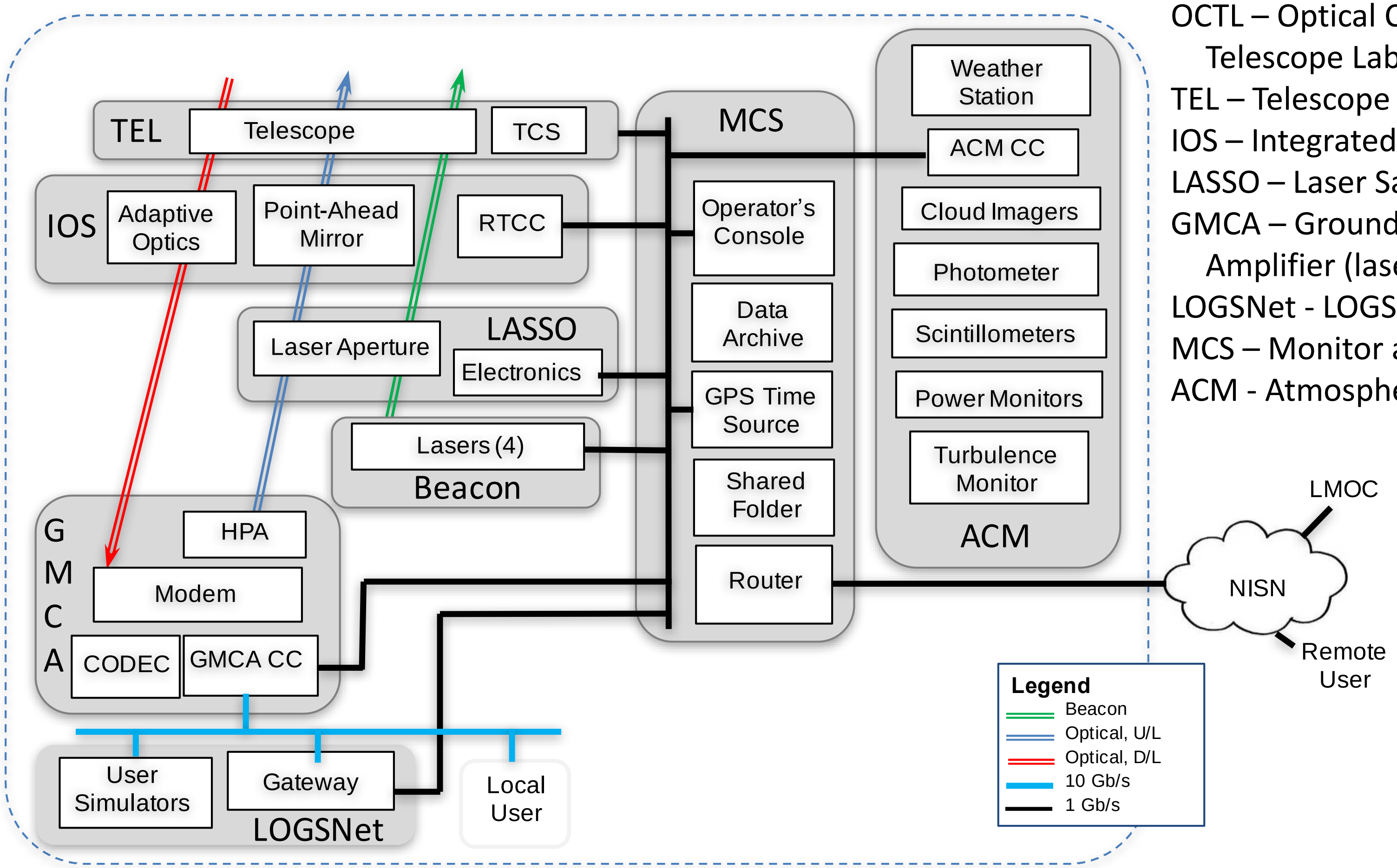
LCRD Developed
OGS-X Developed
Joint LCRD/OGS-X Developed
Host Developed

The LOGS Project

- Adapt the Optical Communications Telescope Laboratory (OCTL) to support LCRD
  - Assure telescope availability requirement
  - Couple light from telescope into single-mode fiber to modem
  - Develop beacon and transmit optics
  - Assure safe operations
  - Coordinate and monitor sub-system operations
- Develop networking hardware and software and simulations to fully exercise the optical link
- Monitor relevant atmospheric conditions and correlate with system performance



OGS-1 Sub-Systems



Dictionary

OGS - Optical Ground Station
LOGS – LCRD Optical Ground Station
OCTL – Optical Communications Telescope Laboratory
TEL – Telescope
IOS – Integrated Optical System
LASSO – Laser Safety System at OCTL
GMCA – Ground Modem, Codec and Amplifier (laser)
LOGSNet - LOGS networking system
MCS – Monitor and Control System
ACM - Atmospheric Channel Monitoring

Optical Communications Telescope Laboratory (OCTL)

- 1-meter telescope in Angeles National Forest
- Gated facility staffed 24/7
- Altitude 2200 meters
- Clear sky view above 10 deg elevation
- Badge-reader access

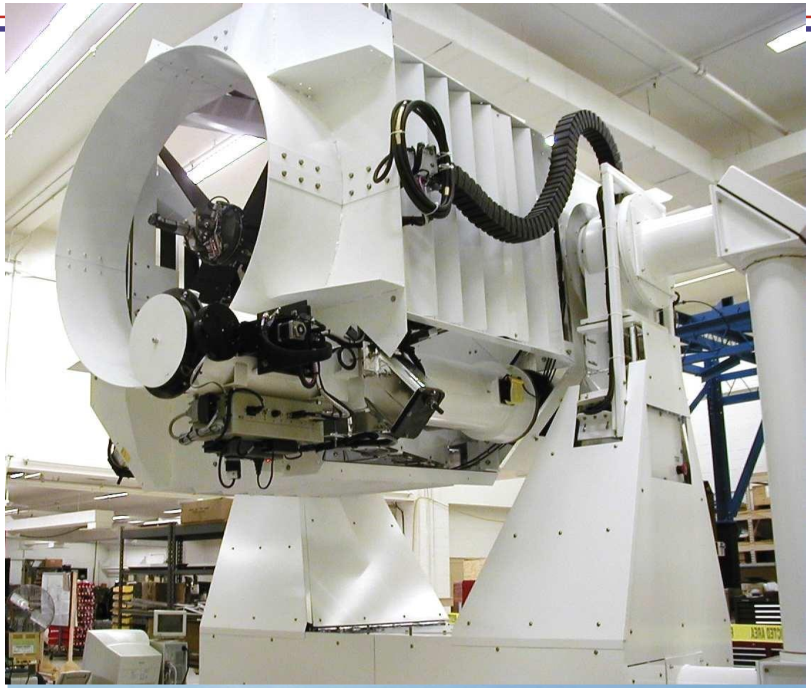
OCTL Telescope

Telescope Design

- 1.0 m Classical Cassegrain telescope
- Athermal Zerodur mirrors
- Denton FSS99 coated optics
- Fast-slewing Az/El mount
- Coude configuration supports multiple concurrent experiments
- F/76 optical path
- White baffling for near-Sun operations
- Spider shields for near-Sun operations
- F/7.5 Newtonian acquisition scope

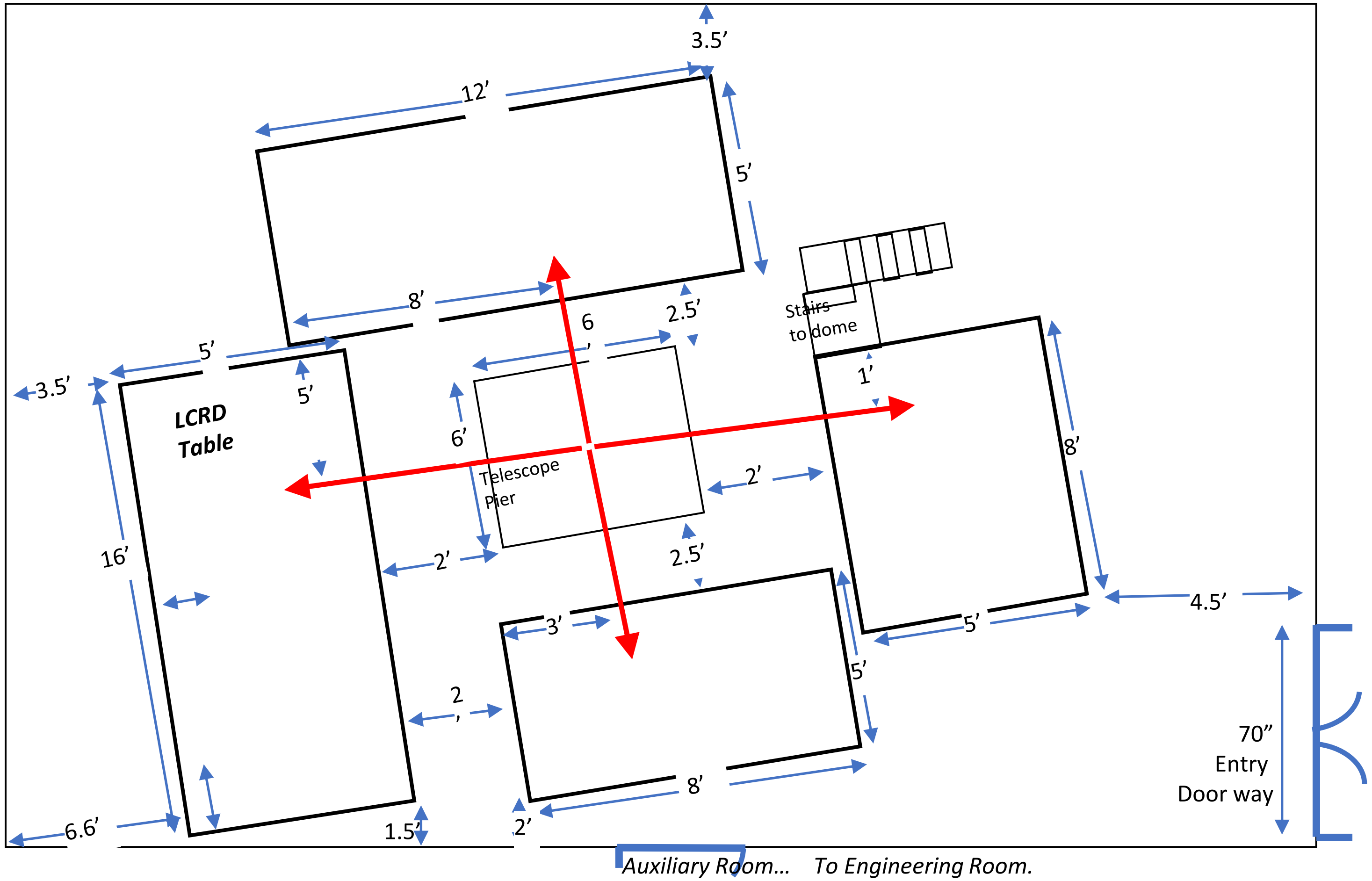
Facility Advantages

- JPL managed controlled facility
    - Perimeter fence
    - 24/7 security
- Close proximity to JPL



Coudé Laboratory

- 4 coudé ports
- LOGS IOS on a 16x5 foot table
- Minimal interference from other experiments
- Enclosed, interlocked pathway to and through telescope



LCRD Communications Equipment in place

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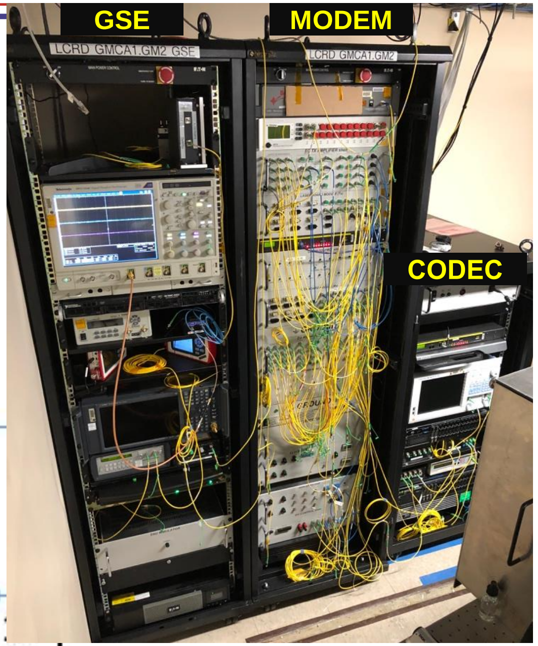
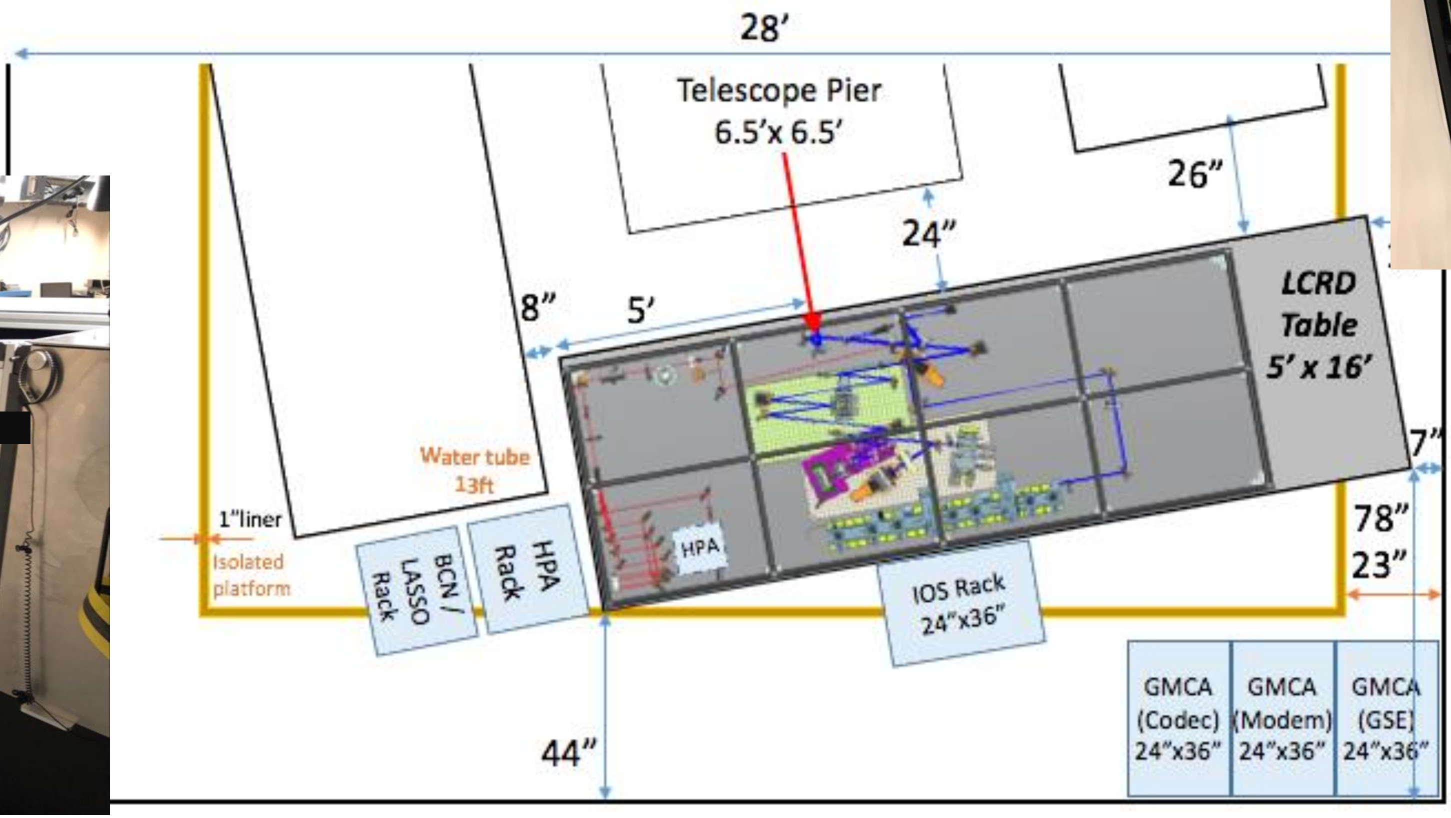
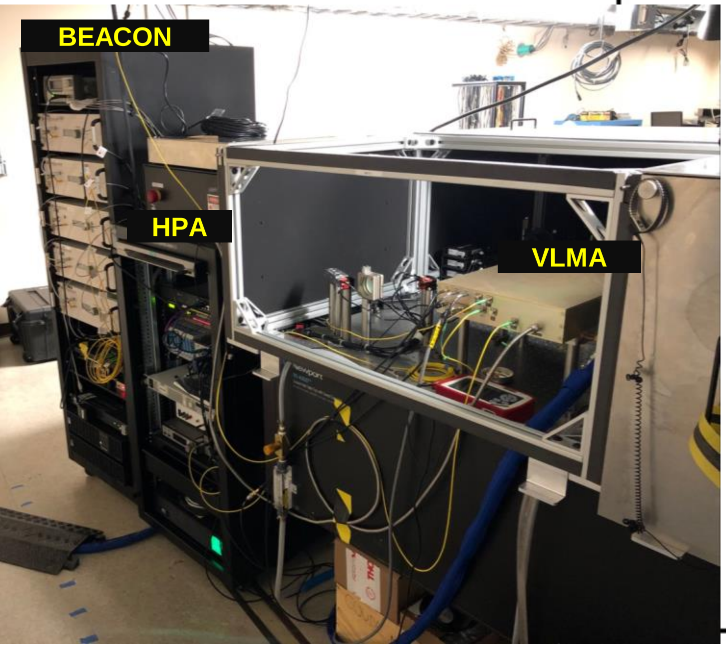
- All equipment received, in place and integrated
- Currently testing the system to verify it meets requirements

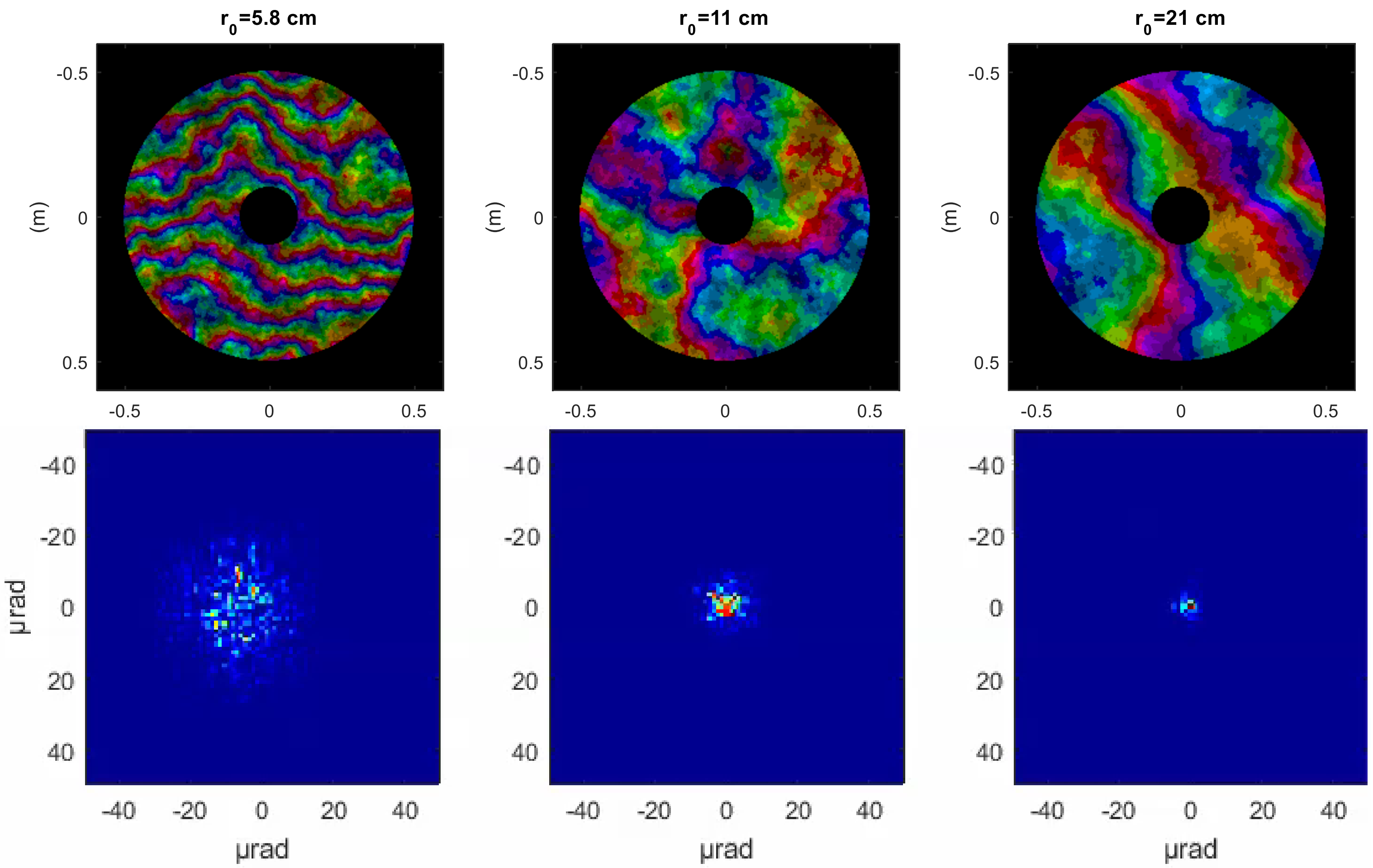






The Need for Adaptive Optics

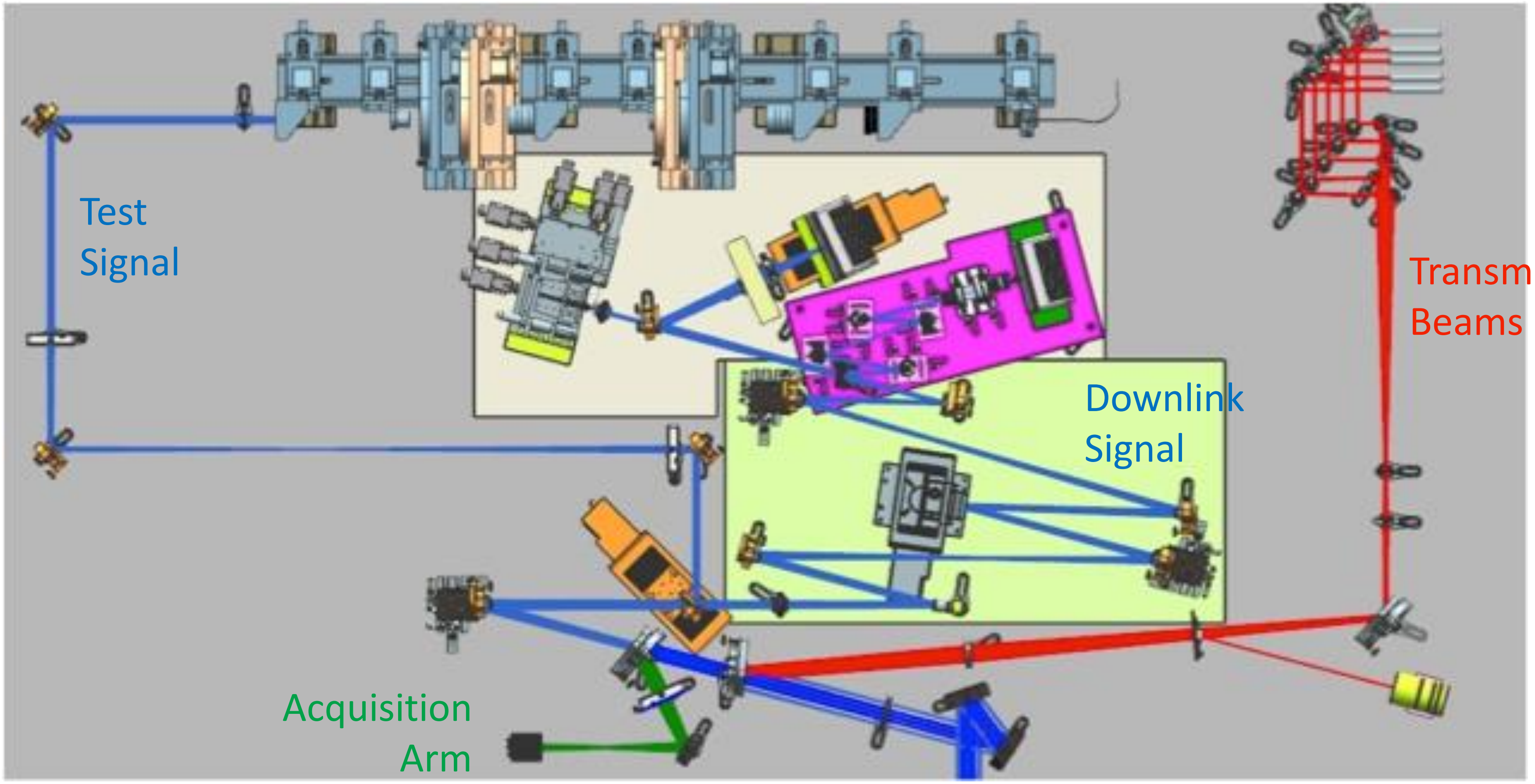
- **Thermal gradients and turbulent winds introduce local refractive index variations**
- **Fried's parameter (r_0) is roughly the diameter of a patch of wavefront over which the phase is relatively constant**
- **We need to flatten the aberrated signal wavefronts to efficiently concentrate them into a single-mode fiber**
- **The way to do that is to use an Adaptive Optics System**



- More turbulence (smaller r_0) cause the spot to broaden and break up
  - Poor coupling to single-mode fiber

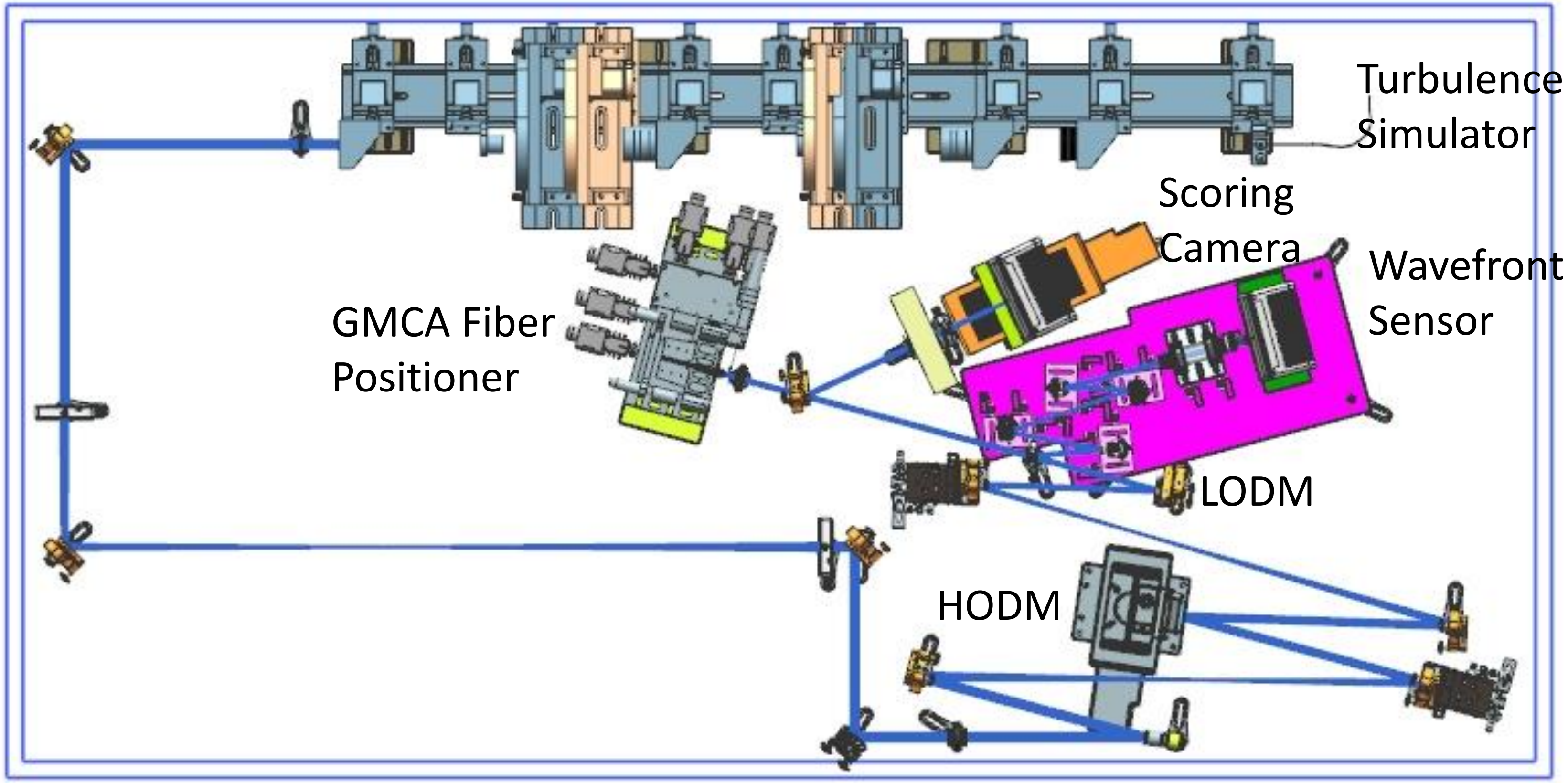
Integrated Optical System (IOS)

- Projects our uplink beacon which allows the flight system to lock onto our location
- Controls the shaping and aiming of the communications uplink beam
- Efficiently couples light from the telescope to the modem



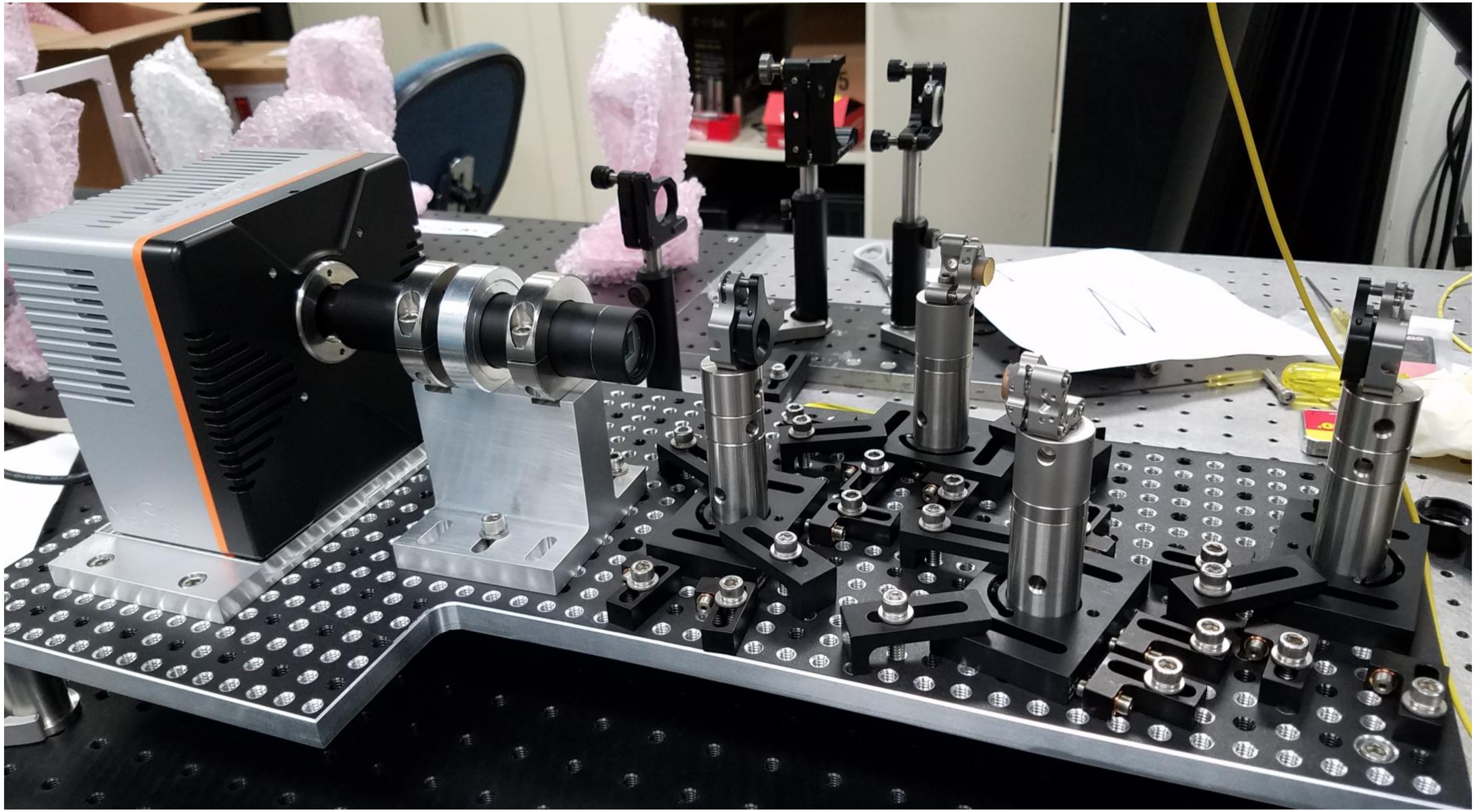
IOS Adaptive Optics System

- **Reimages the telescope pupil (where most wavefront aberration occurs) to:**
  - **Tip-tilt mirror (to correct for image drift and global atmospheric tilt)**
  - **High Order Deformable Mirror (corrects low amplitude, high spatial frequency aberrations)**
  - **Low Order Deformable Mirror (corrects high amplitude, low spatial frequency aberrations)**
  - **Wavefront Sensor (for measuring the wavefront after corrections are applied)**
- **Reimages the far field to:**
  - **The scoring camera (to independently measure how well the system is performing**
  - **The single mode optical fiber (input to the ground modem)**



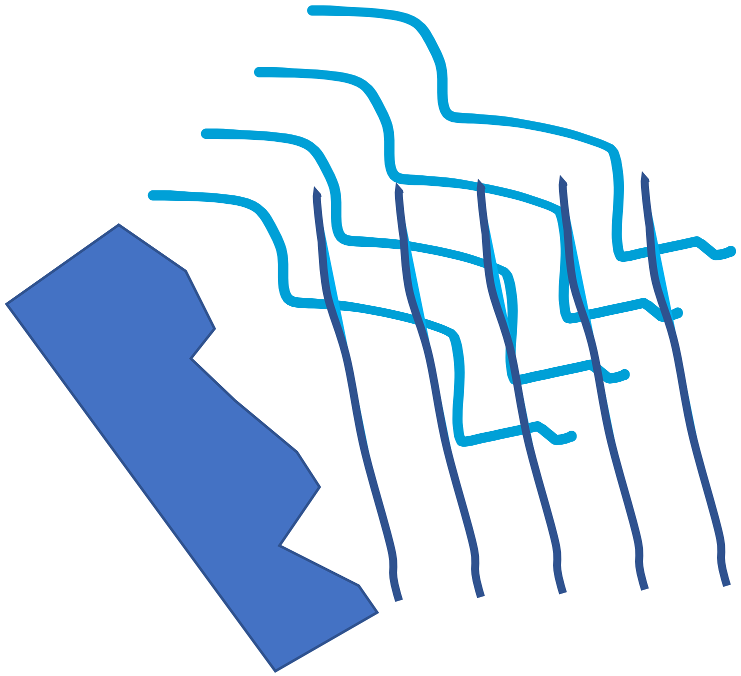
IOS Wavefront Sensor

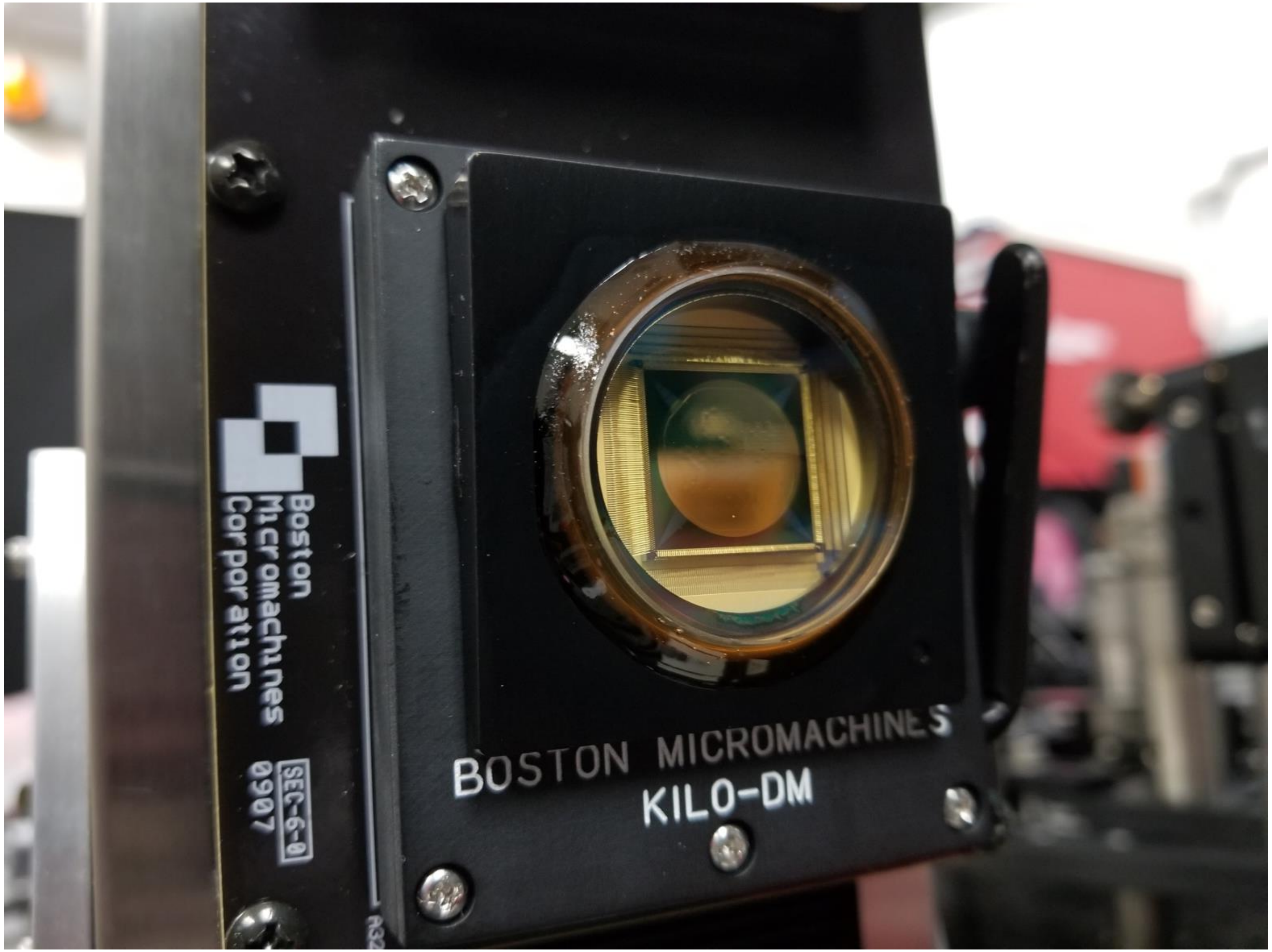
- The Wavefront Sensor generates a map of the incoming wavefront
- It measures the wavefront slope over hundreds of small regions of the beam (subapertures)
- It sends that data thousands of times per second to a computer



Deformable Mirrors

- Once we know the shape of the incoming wavefront, we correct it with deformable mirrors
- We intentionally introduce the opposite shape into the mirror which results in a flat(ter) wavefront





Performance of OGS-1 Adaptive Optics System

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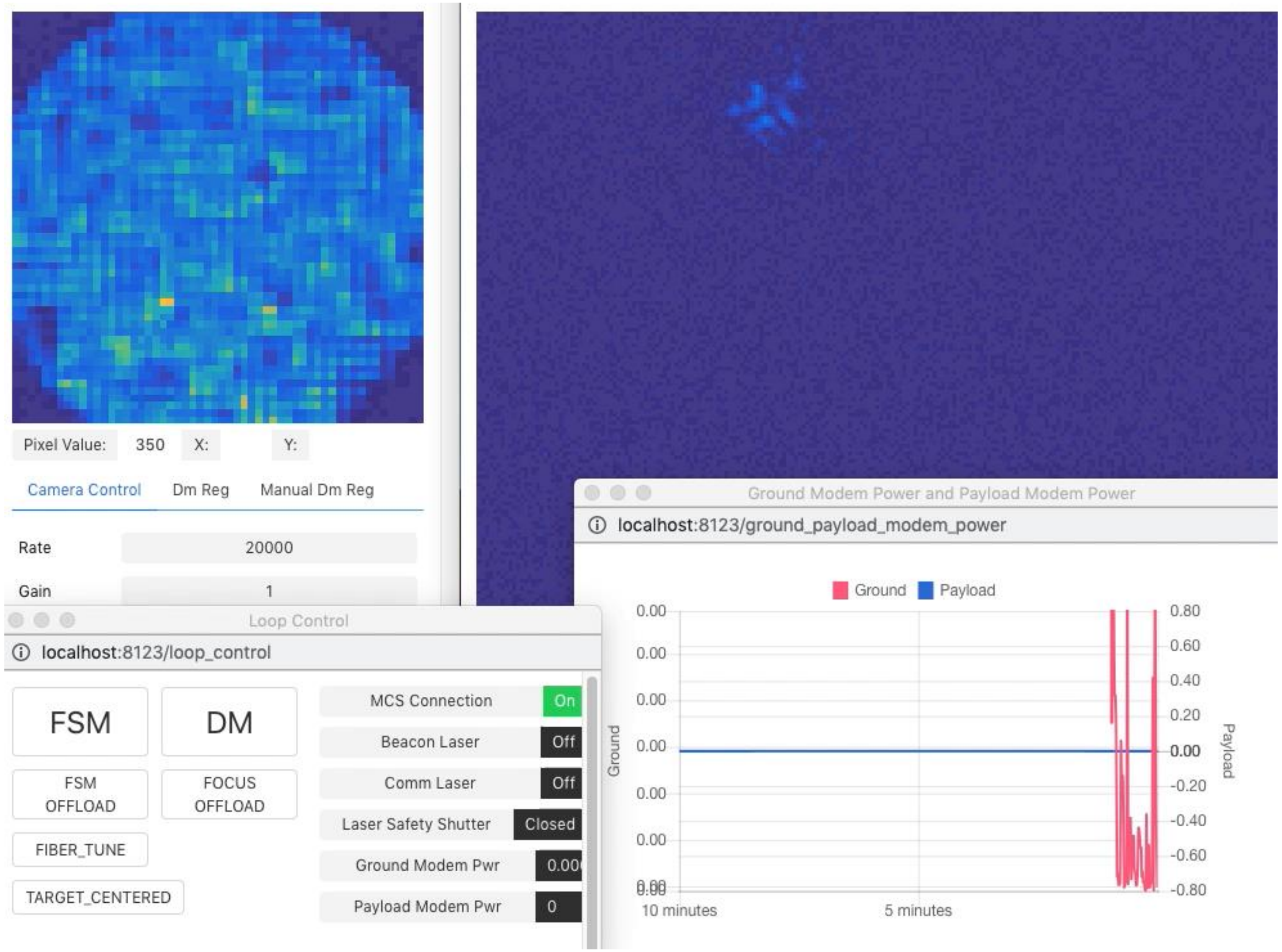
- An Atmospheric Turbulence Simulator (ATS) uses two rotating phase screens to simulate atmospheric turbulence
- A wavefront sensor measures the tilt of the incoming wavefronts across small portions of the telescope aperture
- A fast computer decides what changes are needed to ‘clean up’ the wavefront
- A Fast Steering Mirror (FSM) is used to stabilize beam position
- Two deformable mirrors at pupil conjugate shape the wavefront
- The flattened wavefronts can then be focused into the single-mode fiber



Beacon Lasers

- Provides modulated signal for payload to point to
- Four separate beacon lasers are used to
  - Cover the full blind-pointing uncertainty region of the telescope
  - Reduce beacon laser operating power (longer lifetime)
  - Provide beacon redundancy
- We use commercial fiber-coupled lasers

LAser Safety System at OCTL (LASSO)

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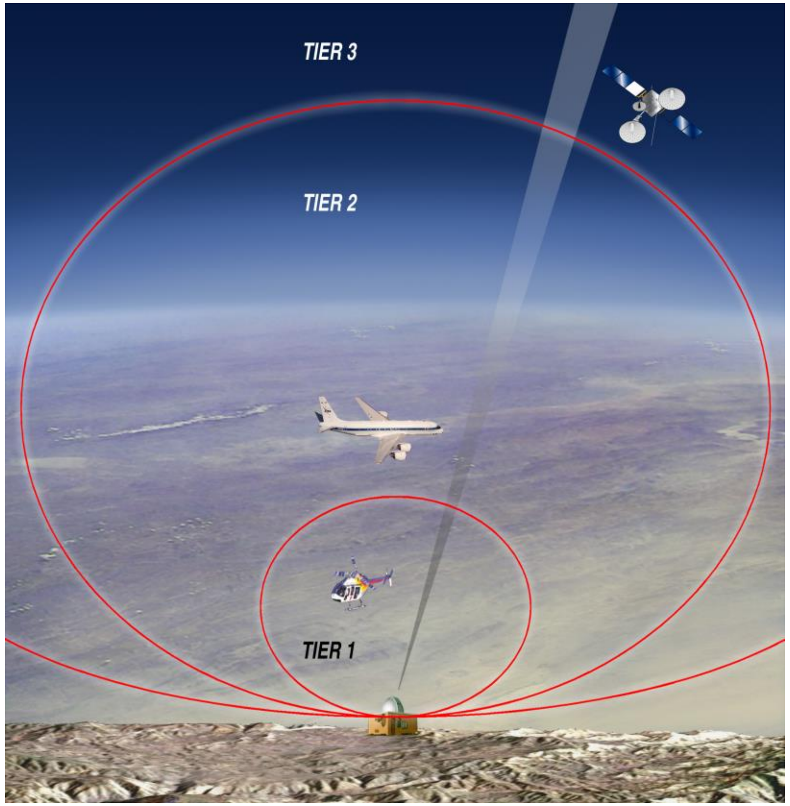
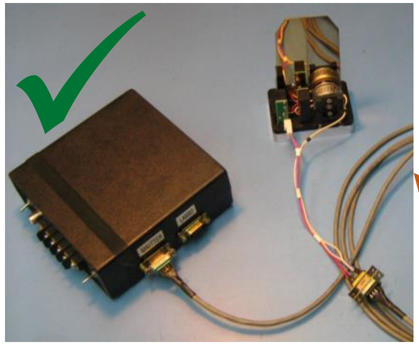
- Prevents unintended illumination of spacecraft
  - Uplink communications beam (10W)
  - Uplink beacon beams (10 W total)
- Failsafe Operation
- Based on legacy outdoor laser safety system
- Provides hooks for future aircraft detection systems
  - Thermal IR cameras
  - Radar
  - ADSB



Shutter Hardware



LOGS
MCS

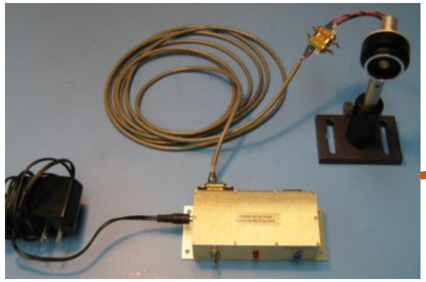
Network

LASSO
Computer

TTL

TTL

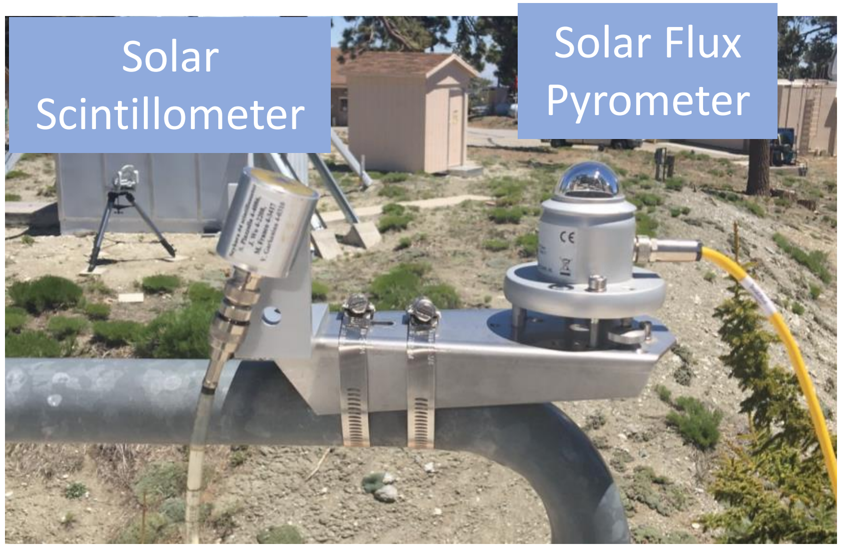
TTL

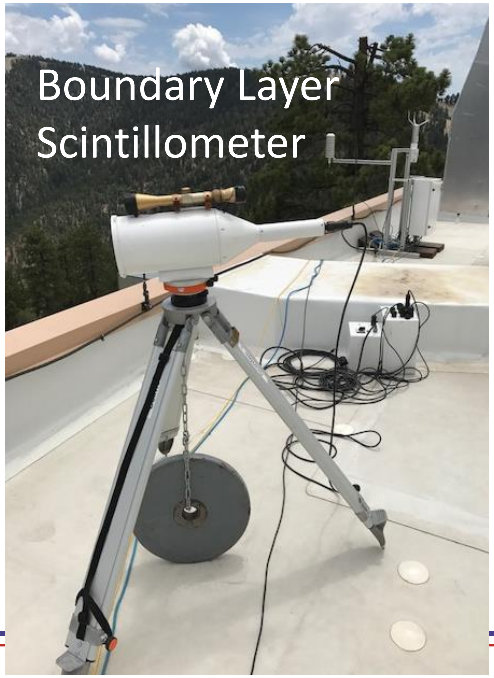


Beam Detector Hardware

Atmospheric Monitoring Equipment

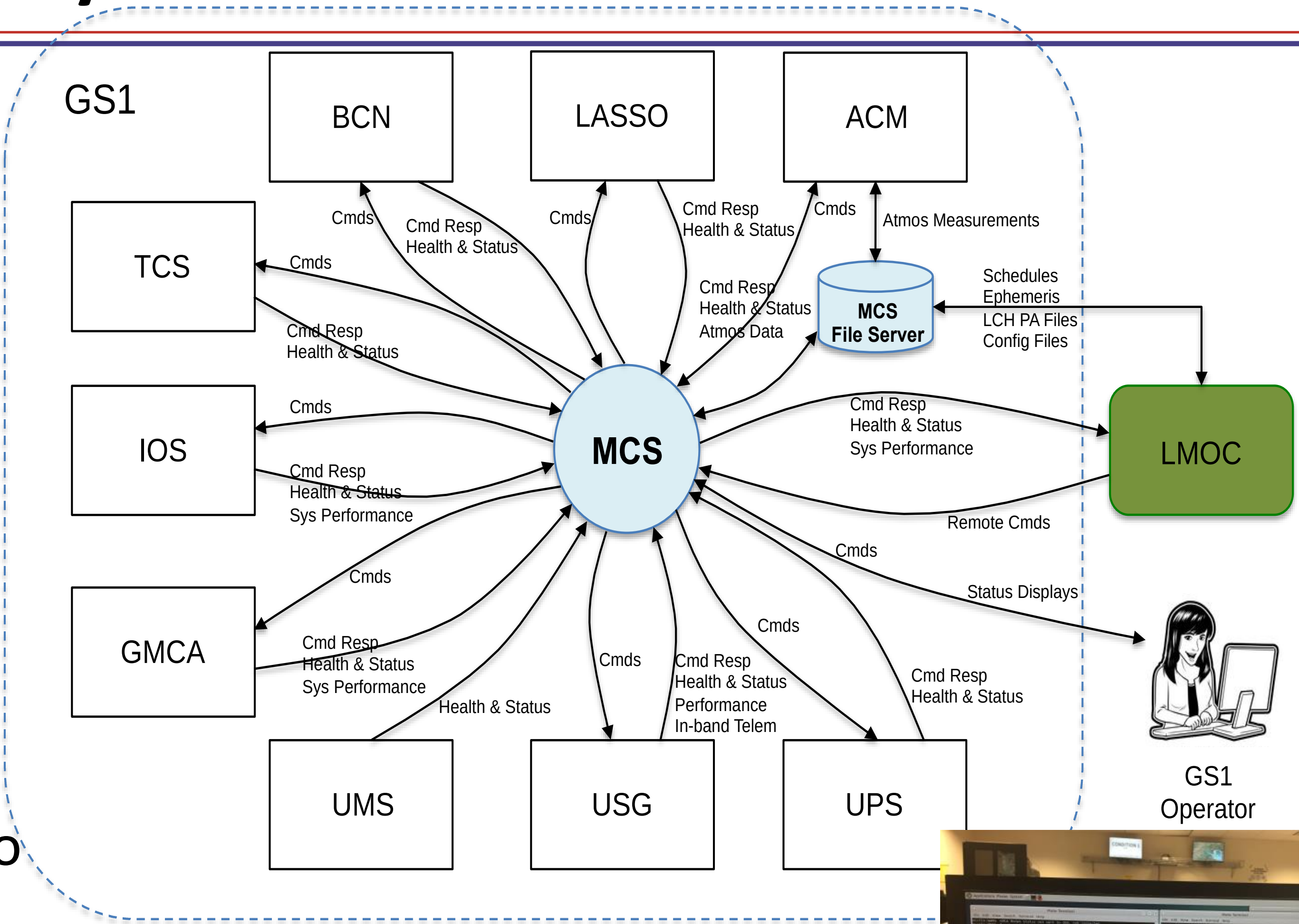
- Equipment for measuring, recording and understanding the atmospheric conditions to later correlate with link performance
- Equipment includes
  - Weather Station for understanding local winds and humidity and protect the facility from weather
  - Particulate Monitor to understand the attenuation and scattering of signal light due to particulates
  - Solar Flux Pyrometer for data on sky background and transmission
  - Solar Scintillometer for measuring the amount of signal beam breakup we have going through the atmosphere
  - Boundary Layer Scintillometer to understand how much turbulence is at the ground
  - ASIVA instrument for measuring cloud cover, cloud depth, sky transmission, water vapor

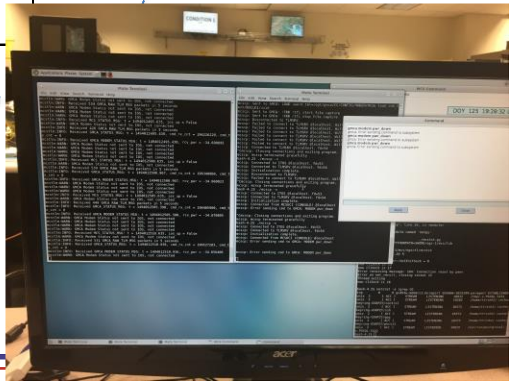




OGS-1 Monitor and Control System

- The Monitor and Control system
  - Configures and prepares other subsystems for operational conditions
  - Allows local controllers to see and control real-time system operation
  - Coordinates the operations with the Mission Operations Center
  - Keeps track of sub-system conditions and performance
  - Reports important information to the LCRD Mission Operations Center





Summary

- We are nearing completion of NASA's primary ground station for the demonstration of a new laser-based communications system
  - Requiring much less size, weight and power
  - Able to reliably transmit data at a much higher rate than ever before
  - Providing much more secure communications
- NASA's Optical Ground Station 1 will be open for experimenters to use
  - We have an extensive set of instruments for understand propagation
    - Through the atmosphere
    - Under many different sky and atmospheric conditions
    - All times of day and night
    - Through all seasons
- This paves the way for future optical communications systems in Earth orbit and beyond

Acknowledgments

- Sponsors at the NASA Space Communication and Navigation Office
- Support of Section 337 – Flight Communications Systems
- Support at the Table Mountain Facility
- Colleagues in JPL Groups 337E, 383F, 312I, 3320, and 393G
- Colleagues at Goddard Space Flight Center